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THE EFFECT OF ACCELERATION ON THE BURNING RATES OF COMPOSITE AND DOUBLE BASE SOLID PROPELLANTS

by

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Monterey, California

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ABSTRACT:

Under contract NavWeps 4235/6, the Naval Postgraduate School is conducting four experimental investigations: (1) The effect of propellant strand size on the experimentally measured burning rate at various acceleration levels; (2) an investigation of the effect of initial propellant temperature on acceleration induced burning rate augmentation; (3) an investigation of the effect of nominal burning rate on acceleration induced burning rate augumentation; and (4) a photographic investigation of augmented burning rate.

Significance of the investigation and a brief review of the literature are presented.

The apparatus employed in these investigations is discussed in references 5 and 7. The test program for the propellant strand size investigation is presented.

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A STUDY OF THE EFFECT OF ACCELERATION ON THE BURNING RATES OF COMPOSITE AND DOUBLE BASE SOLID PROPELLANTS

Significance

High performance intercept missiles require large accelerations to accomplish their mission. In addition to the propellant in the main rocket motor, there may be hot gas generators for actuating controls and providing power. These auxillary hot gas generators are also subject to the high acceleration. Consequently it is necessary to examine a wide variety of propellants.

One possible means of stabilizing high altitude sounding rockets and rocket assisted projectiles is to spin the vehicles about their longitudinal axes. At the spin rates necessary for the required stabilizing effect, the acceleration effect on the burning of a cylindrical propellant grain may be considerable.

The experimental results reported by several investigators[1,2,3,4,5,7,10,14] indicate that acceleration directed normal to and into the burning surface of a composite solid propellant has a significant effect on the burning rate. In the centrifugal force fields resulting from spin or from linear acceleration, there is evidence to indicate that the propellant burning rate may be increased by several hundred percent for some composite propellants[5,7,9,10].

A relative change in burning rate of this magnitude will have a significant effect on the motor thrust, chamber pressure, and the burning time. Hence, in order to properly design a motor which will be subjected to acceleration while burning, effects of acceleration must be known.

Brief Review of Literature

Several investigators have experimentally studied the effect of propellant composition, pressure, and the nominal burning rate (r_o) on the acceleration induced burning rate augmentation (r/r_o) of composite

solid propellants[5,6,7,8,9,10,14,15]. Most of the experimental work has been concerned primarily with metallized composite propellants although some work has also been done with non-metallized propellants.

Analytical models for acceleration induced burning rate augmentation have also been proposed. Crowe[9] has proposed a model for aluminized propellants. Glick[12], Sturm[7,8] and Reichenbach[8] have proposed models for non-aluminized composite propellants.

Crowe's model for the burning of aluminized composite propellants is summarized as follows: The analytical model considers the opposing forces on the aluminum agglomerates of the centrifugal force (into and perpendicular to the burning surface) and the drag force (from the gases leaving the surface). A particular aluminum agglomerate will burn until it reaches the size where the centrifugal force equals the drag force. The agglomerate then leaves the burning surface and no longer contributes to the combustion process at the surface. The larger aluminum agglomerates are held on the surface and increase the energy release at the surface and the energy transfer from the gas phase to the solid or molten phase. According to the model, anything that reduces the size of the aluminum agglomerates would reduce the effect of acceleration on the burning rate.

Qualitative results have been obtained[9,10] which indicate that the proposed model has merit but other investigators[5,6,7,8] have not been able to correlate their experimental data with Crowe's model.

The experimental results of Crowe et.at.[9,10] for aluminized composite propellants have indicated the following: (a) The higher the nominal burning rate (r_o), the less sensitive the burning rate is to acceleration forces. It is reasoned that the higher normal surface gas velocity which exists for the higher burning rate propellants forces more of the aluminum agglomerates from the burning surface at any particular acceleration level. Higher nominal burning rates (r_o) can be obtained by decreasing the AP crystal size and/or by adding burning rate

catalysts; (b) a smaller AP crystal size also reduces the size of aluminum agglomerates on the surface because the "binder pockets" are smaller; (c) burning rate augmentation (r/r_o) decreases with decreasing pressure. It is reasoned that this effect results from the higher normal gas velocities at the propellant surface attained at the lower pressures; (d) a critical "flooding" condition can occur in which the entire burning surface is covered with aluminum. In this condition the normal combustion process is interrupted and the burning rate decreases[7,8,9,10].

The experimental results of Sturm, Anderson, and Reichenbach[5,6,7,8] for aluminized composite propellants are summarized as follows: (a) The burning rate decreases as the strand burns. This result is attributed to surface "flooding" by the aluminum; (b) burning rate augmentation (r/r_o) is not a consistent function of pressure; (c) burning rate augmentation shows no consistent trend with initial propellant temperature; (d) burning rate augmentation is not a function of acceleration level for fast burning rate propellants; (e) the primary factor affecting flooding was the aluminum particle size.

Sturm and Reichenbach's[7,8] model for non-metallized composite propellants is summarized as follows: Because the Summerfield granular diffusion flame model[11] does not correctly explain some experimental observations at higher than 1-g acceleration levels, Sturm[7] extended Fenn's model[13] for the burning of composite propellants. It was assumed that a similar situation occurred with respect to AP crystals as Crowe assumed to occur for the aluminum agglomerates. The larger AP crystals are held on the surface by the acceleration field, enhancing the burning rate. The smaller AP crystals leave the surface (drag forces greater than acceleration forces) and are lost with regard to the surface combustion process. The AP crystals are considered "unattached" to the surface because the combustion process has proceeded completely around the binder - AP crystal interface before the AP crystal is consumed.

Sturm and Reichenbach were able to correlate their experimental results for non-metallized propellants with this model.

The experimental results of Sturm and Reichenbach[7,8] for non-metallized propellants are summarized as follows: (a) Burning rate augumentation is significant when the acceleration force is directed perpendicular and into the burning surface; (b) no time dependence of burning rate was found for various strand lengths; (c) burning rate augmentation increases with increasing initial propellant temperature; (d) burning rate augmentation increases with increasing pressure.

Crowe, et.al. obtained their data by utilizing a rotating and internally burning solid propellant grain. The disadvantage of this experimental procedure is the large change in the acceleration level as the propellant burns. Only the average acceleration effects can be obtained. The advantage of their apparatus is that it simulates an actual motor configuration.

Sturm and Reichenbach employed end burning strands to obtain their experimental results. A large centrifuge with surge tanks was employed to minimize the variation of pressure and acceleration level during a particular test. The disadvantage of this method is that the propellant strand may not correctly indicate the burning rate which would exist in an actual motor configuration.

Investigations Required for Better Understanding of Problem

A. The effect of strand sample size on the experimentally measured burning rate at various acceleration levels.

This work is required in order to better understand the applicability of data obtained with propellant strands and to correlate the data obtained by the various investigators.

B. The effect of initial propellant temperature on burning rate augmentation.

In addition to determing the effects of environmental changes

on burning rate augmentation this study would enhance the understanding of the coupling between available energy and burning rate.

C. The effect of nominal burning rate on acceleration induced burning rate augmentation.

Although some work has been done in this area a controlled series of tests is needed in which the burning rate is varied over a large range. This study should include: (1) metallized and non-metallized composite propellants in which the AP crystal size and percent catalyst are varied and (2) double-base propellants in which the percent catalyst is varied. This study would yield a better insight into the basic mechanisms causing burning rate augmentation.

Analytical investigations are also necessary to supplement the experimental work. The idea of opposing acceleration and drag forces on solid particles (aluminum in Crowe's model and AP in Sturm and Reichenbach's model) needs further investigation. Since qualitative agreements between theory and experiment have been obtained by Crowe and Sturm, a model for aluminized propellants incorporating the simultaneous effect of acceleration on the AP crystals and aluminum agglomerates should be investigated. The double-base investigation would yield insight into the effects of acceleration on the gas-phase reactions and would eliminate the energy feedback through the metal agglomerates and/or other solid particles.

D. Photographic investigation of augmented burning rate.

This investigation is required in order to gain a better physical understanding of the methods of aluminum ignition, aluminum agglomeration, particle "blow-off" from the surface, and fuel "pit" formation. Several studies are currently being conducted in this area[15,16].

Objectives of Current Program

The immediate objectives of the current program are to systematically investigate items A. through C. listed above. In addition a

photographic investigation will be initiated.

Progress to Date

The effect of strand sample size on the experimentally measured burning rate at various acceleration levels is currently being studied. Strand cross-section is being varied from .2 x .2 inches to 1.0 x 1.0 inches and strand length is being varied from .5 inches to 2.0 inches. A metallized composite propellant (NOTS X-32) is being employed in this study in which the pressure level is being varied from atmospheric to 1500 psi and the acceleration level is being varied from 0 to 1500 g's.

Strands have also been fabricated from United Technology Propellant UTX-3096A, and burning rate augmentation data is being obtained with the Naval Postgraduate School centrifuge. These tests are being conducted in order to compare the centrifuge data with that obtained by UTC for the same propellant but with an internally burning grain subjected to various acceleration levels.

The above investigations will be completed by the next report period.

The investigations of items B. and C. are currently being initiated.

The photographic investigation of burning propellants subjected to acceleration will begin in the third quarter of the program.

References

1. "An Investigation of the Effects of Acceleration on the Burning Characteristics of Solid Propellants," Report Nos. KPR-3, KPR-4, KPR-5, Contract No. AF33 (616) 6779, Project No. 3059.
2. Guthrie, W. D. and Chen, E.C.M., "Effects of Acceleration on Burning Rates of Solid Propellants," Report No. RK-TR-63-22, 1 Oct 1963, Defense Documentation Center, Alexandria, Va.
3. Vecchio, R., "Static Spin Testing of Solid Rockets," Bulletin of 1st Meeting of Interagency Rocket Propulsion Groups working on Static Tests, 16-18 Oct 1963.

4. Iwanciow, B. L., Lawrence, W. J., and Mertens, P., "The Effect of Acceleration on Solid Composite Propellant Combustion," AIAA Paper No. 64-227.

5. Anderson, J.B., "An Investigation of the Effect of Acceleration on the Burning Rate of Composite Propellants," Ph.D. Thesis, Naval Postgraduate School, August 1966.

6. Anderson, J. B. and Reichenbach, R.E., "An Investigation of the Effect of Acceleration on the Burning Rate of Composite Propellants," AIAA Journal, 6, pp 271-277, 1968.

7. Sturm, E.J., "A Study of the Burning Rates of Composite Solid Propellants in Acceleration Fields," Ph.D. Thesis, Naval Postgraduate School, March 1968.

8. Sturm, E.J. and Reichenbach, R.E., "An Experimental Study of the Burning Rates of Aluminized Composite Solid Propellants in Acceleration Fields," Presented at the 1968 ICRPG/AIAA 3rd Solid Propulsion Conference, Atlantic City, New Jersey, 4-6 June 1968.

9. Crowe, C., and Willoughby, P., "Effect of Spin on the Internal Ballistics of a Solid Propellant Motor," AIAA Paper No. 66-253 (presented at the AIAA Fourth Aerospace Sciences Meeting (West Coast), June 27-29, 1966)

10. "Investigation of Performance Losses and Ballistics Effects in Solid Propellant Rockets," UTC2197-FR (Naval Ordnance Systems Command Contract No. Now 66-0444C), United Technology Center, Sunnyvale, California, April, 1967.

11. Summerfield, M., et.al., "Burning Mechanism of Ammonium Perchlorate Propellants," Progress in Astronautics and Rocketry, Vol. 1, New York: Academic Press, 1960, p. 142.

12. Glick, R., Hodge, B., and Caveny, L., "Effect of Acceleration on the Burning Rate of Composite Propellants," AIAA Paper No. 67-470 (presented at the AIAA Third Joint Propulsion Specialist Conference, Washington, D. C., July, 1967)

13. Fenn, J., "A Phalanx Flame Model for the Combustion of Composite Solid Propellants," Project Squid Technical Report PR-114-P, April, 1967.

14. Northam, G., "An Experimental Investigation of the Effects of Acceleration on the Combustion Characteristics of an Aluminized Composite Solid Propellant," Proceedings of the ICRPG/AIAA Solid Propulsion Conference, CPIA Publication No. 111, Vol. II, Washington, D.C., July, 1966, p. 129.

15. "Investigation of Internal Ballistics Effects in Spinning Solid Propellant Motors," UTC 2281-QTR 1 (Naval Ordnance Systems Command Contract No. N00017-67-C-2429), United Technology Center, Sunnyvale, California, August 1967.

16. "An Optical Bomb Study of the Combustion of Solid Propellants in High Acceleration Fields," TR-PL-9650 (Office of Naval Research Contract No. N00014-67-C-0455), Atlantic Research Corporation, May 1968.

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